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THE EFFECTS OF FLUCTUATING TEMPERATURE STORAGE ON THE ACCEPTABILITY OF MEAL, READY-TO-EAT COMPONENTS

by

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13. ABSTRACT *(Maximum200words)*

The purpose of this investigation was to determine if extreme fluctuating conditions would cause significant deterioration of MRE components as measured by technical sensory observations and consumer panel acceptability ratings. Twenty components - eight entrees, three fruits, three baked/snack and six sugar or artificially sweetened powdered beverages - were studied. A controlled-temperature cabinet, capable of temperatures from -18 °C (0° F) to 177°C (350° F) was used. The foods were subjected to six, 14-day temperature cycles, adjusted incrementally on weekdays, ranging from -18° C (0° F) to 49 °C (120° F). Extreme temperatures were held for 72 periods on weekends. After each cycle, all components were examined for sensory changes. Consumer panels were conducted after the sixth cycle and compared to the same components stored at constant 4° C (40° F) for the same time period. Sensory changes were generally minor for most components after six cycles. However, for six foods (two chicken-based entrees, two fruits, a baked item and a citrus flavor beverage, ratings for fluctuating-temperature stored samples were significantly lower than for constant-temperature equivalents. Effective mean temperature computations are given. Based upon the computations and the observed amount of deterioration, the fluctuating-temperature program was estimated to be equivalent to constant three months/38° C (100° F).

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Preface

This research was conducted under the research element Food Stabilization and Shelf Life Indices for Military Subsistence Feeding in Environmental Extremes, Science and Technology Objective (STO) III.P12, Project Number 07 BBOG 1L162724AH99, Accelerated Testing work unit, during 1 December 1994 to 31 March 1995. The authors thank the following individuals for their assistance: Ms. Ruth Roth and Ms. Shivaun Roche, Science and Technology Directorate, Natick RD&E Center, for conducting the consumer sensory analyses; Mr. Ronald Ingelby and Ms. Janine Campbell, Sustainability Directorate, for setting up and maintaining the storage chamber; and Dr. Edward Ross, statistical consultant, for data analysis. The original draft was prepared by Ms. Carol Shaw; revision and publication was completed by Mr. Robert Kluter.

The Effects of Fluctuating Temperature Storage on Acceptability of Meal, Ready-to Eat Components

INTRODUCTION

The program, Food Stabilization and Shelf Life Indices for Military Subsistence Feeding in Environmental Extremes, was established to address field ration quality problems, particularly the semiperishable Meal, Ready-to-Eat (MRE). Military engagements in the early 1990's in Saudi Arabia, Kuwait, Panama, Haiti, and Somalia heightened awareness of the deleterious effects on quality of this ration after prolonged exposure to extreme hot weather environments during distribution and storage. The U.S. Department of Defense requires that field rations and other semiperishable subsistence items withstand distribution, storage and use under highly variable climatic conditions including Arctic, desert, temperate and jungle. Rations must remain stable when exposed to temperatures (1) below freezing, (2) at or sometimes exceeding, 49°C (120°F), and (3) including freeze/thaw cycles. Thus, it is advisable to consider extreme, especially high, temperatures as well as fluctuating temperatures when assessing ration shelf life.

The standard requirement for semiperishable military rations is that they be acceptable after storage for three years at 26.7°C (80°F) and six months at 38°C (100°F). This contrasts with food industry requirements for consumer products where one-year shelf life is generally considered sufficient and six months more typical for semiperishable food items. Operational rations are stored both in the United States and around the world as Prepositioned War Reserve Stocks in case of emergency military actions. If no emergency arises, they are inspected for condition and, if approved for consumption, rotated out and consumed during military training exercises. Cost effectiveness increases if storage time can be extended. However, rations must continue to be acceptable to military consumers.

Under the Accelerated Testing work unit, constant temperature storage studies were conducted at 4.5, 26.7, 38, 49 and 60°C (40, 80, 100, 120, and 140°F, respectively) to estimate the rates of quality degradation. Hot climate studies were also conducted on MRE rations held in three container vans at Yuma Proving Ground, Yuma AZ. Thermocouples, placed at various locations among cases inside the vans, recorded temperatures (Porter et al., 1993), and ration samples were periodically removed for sensory analysis. MRE rations stressed during storage at other locations were also evaluated. These included: Operation Desert Shield/Storm (ODS), Ft. Campbell KY and from Prepositioned War Reserve stocks stored aboard ship.

Although rations stored under ambient conditions such as Yuma and ODS were subjected to naturally occurring fluctuating temperatures, controlled fluctuating tests potentially allow more systematic evaluation of rates of quality degradation over time. Under actual storage conditions

following production, rations may or may not be held at constant temperature storage initially in warehouses. Subsequently, they are likely to be held under wide ranges of climatic conditions as they are shipped, stored and utilized around the world.

Storage at fluctuating temperatures is generally considered more detrimental to food quality than at constant temperatures. Labuza (1979) addressed the theoretical kinetics involved in fluctuating temperature storage and found (1) that when zero and first order equations were applied to an example deterioration of a semi-perishable food, differences between order of reaction were small up to 60% loss and (2) that the average temperature between two extremes in a fluctuating situation, which might be akin to constant temperature storage, *under predicts* the extent of reaction. Rajkowski and Marmer (1995) studied *Escherichia coli* under fluctuating and constant temperatures and found that growth curves at fluctuating temperatures more closely approximated higher rather than the midpoint temperature ranges. Other studies of food items have focused more on frozen foods (Scott and Heldman, 1990, Aparicio-Cuesta et al., 1989) than on foods usually stored at ambient temperatures.

One previous Natick RD&E Center study directly assessed the effects of fluctuating temperature storage on military rations (McNutt and Lee, 1974) on early MRE components. The authors noted relatively few changes in 39 MRE items stored through six test cycles. Each test cycle comprised (a) freezing at approximately -54°C (-65°F) for 16 hours (b) thawing at room temperature [about 21°C (70°F)] for 24 hours (c) holding at 52°C (125°F) for two hours and (d) cooling to and holding at room temperature for an unknown period of time, but likely sufficient to complete a 48-hour cycle. From the quality score sensory ratings of 10 food technologists, the authors noted that beef stew and chicken a la king were most affected: sauces broke down and vegetable texture softened. Very likely, the relatively few deteriorative changes noted were due to the short duration of high-temperature exposure.

The purpose of this investigation was to determine if extreme fluctuating conditions would cause significant changes in MRE components as measured by technical sensory observations and consumer panel acceptability ratings. Because of the small degree of deterioration noted by McNutt and Lee, it was decided to subject ration components to the extreme temperatures of the cycles, particularly the high temperature, for longer durations.

MATERIALS AND METHODS

A controlled temperature cabinet capable of a -18°C (0°F) to 177°C (350°F) range was used for the study. The cabinet, manufactured by BMA Inc. (Model TH-27), had an interior capacity of 27 ft^3. The temperature of the box was manually set at 0700 hours each morning according to the 14-day schedule given in Table 1. One cycle consisted of: (1) an initial 72 hours

of storage at 49°C (120°F); (2) four 24-hour periods at decreasing constant temperatures; (3) 72 hours of storage at -20°C (0°F); and four 24-hour periods of constant temperatures increasing to the initial level. This cycle not only eliminated the need to adjust temperatures over weekends but also permitted longer periods at the extremes of the cycle [-18°C (0°F) and 49°C (120°F)]. Thus, during each 14-day cycle, there was one freezing and one thawing sequence. Samples were removed for informal sensory examination after each 14-day cycle for six cycles. At the end of the sixth cycle all remaining samples were removed from the cabinet.

Table 1. Storage Cabinet Temperature Settings and Times

Day of Week	Temperature, °C(°F)	Hours
Friday	49 (120°)	72
Monday	38 (100°)	24
Tuesday	26.7 (80°)	24
Wednesday	4 (40°)	24
Thursday	-6.7 (20°)	24
Friday	-18 (0°)	72
Monday	-6.7 (20°)	24
Tuesday	4 (40°)	24
Wednesday	26.7 (80°)	24
Thursday	38 (100°)	24
Friday, etc.	49 (120°)	72

Temperatures inside the cabinet were recorded by a Hobo Data Logger and/or a Ryan recorder placed on a wire rack in the center of the box. The internal temperatures to which the foods were being exposed were measured by sealing a Hobo Data Logger inside a plastic pouch and placing this pouch inside an MRE pouch containing applesauce. Figure 1 indicates the temperatures recorded inside the temperature-controlled box during the first of the six cycles, and Figure 2 indicates temperatures inside the filled pouch during the same cycle. Cabinet air temperatures and indicator pouch temperatures were close, as indicated in Table 2.

Table 2. Cabinet Air and Pouch Interior Temperatures

	Cabinet,°C (°F)	Pouch,°C (°F)
Mean	14.7 (58.4)	14.6 (58.3)
Maximum	48.1 (118.6)	47.6 (117.7)
Minimum	-20.9 (-5.7)	-20.2 (-4.4)

Figure 1. Air temperature in temperature-controlled box, cycle one

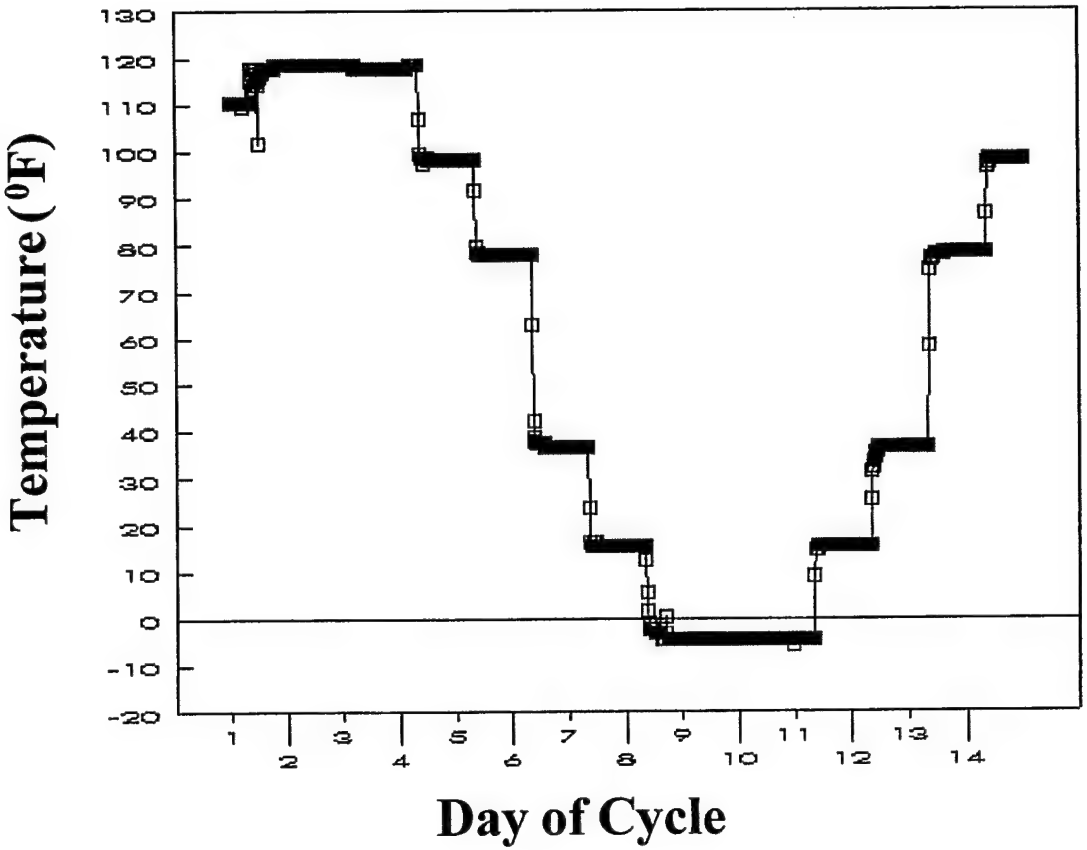
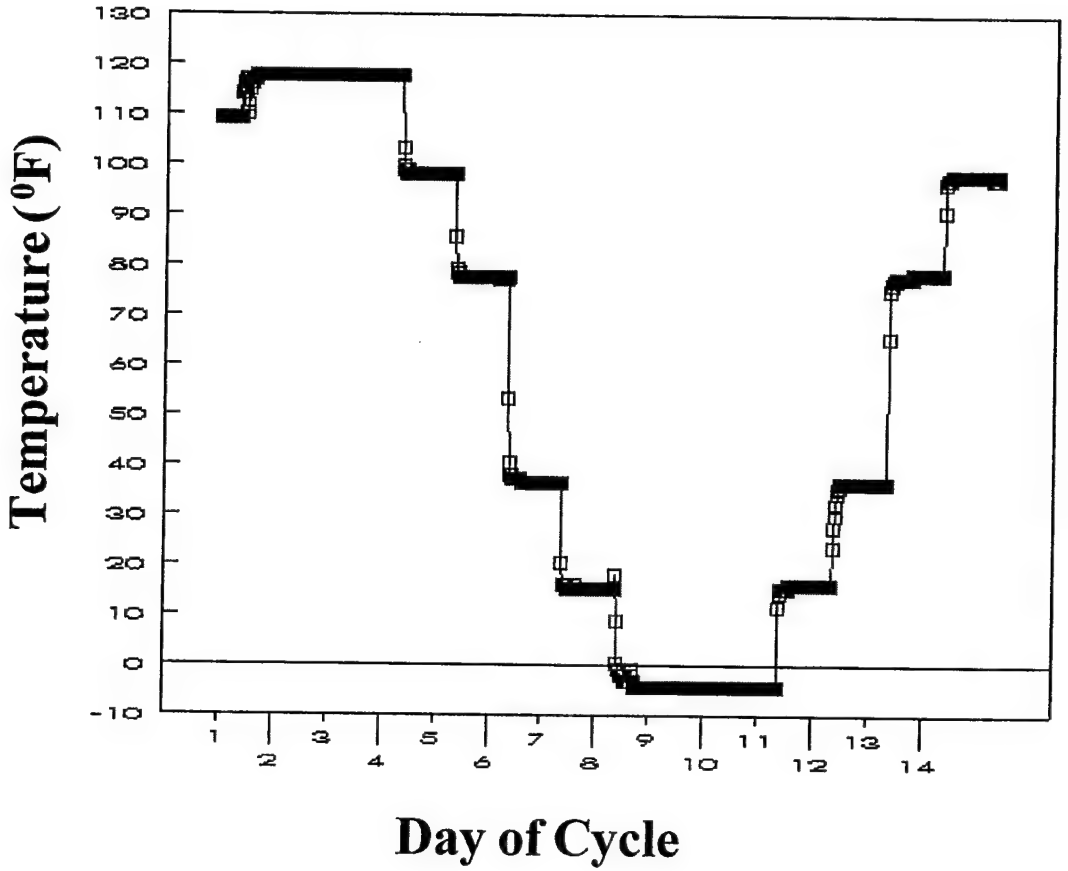


Figure 2. Temperature in sealed pouch in temperature-controlled box, cycle one



The complete MRE XII meals for these tests were commercially manufactured and obtained through the military procurement system (Defense Personnel Support Center). Pouches of the selected components were removed from the meal bags and placed in open corrugated boxes to prevent direct contact with the wire racks in the cabinet. Fiberboard sleeves were not removed from entree items. Boxes were then placed in the chamber. Duplicate MRE XII components were placed in a 4°C (40°F) constant temperature storage to serve as controls for the sensory tests.

After each 14 day cycle, all components of the 12 MRE menus were examined by two or three food technologists for sensory changes compared to the constant temperature stored samples. A complete set of samples held at 4.4, 26.7, 38 and 49°C (40, 80, 100 and 120°F) constant temperature storage was also available for sensory comparisons if needed.

After six 14-day storage cycles (12 weeks), representative components were removed from the cabinet and presented to consumer panels for acceptability evaluation. The panels consisted of 35 to 40 untrained panelists randomly selected from a list of military and civilian personnel who had previously volunteered for sensory tests. Panels consisted predominantly of civilian personnel. They rated degree of liking or disliking for each item on a 9-point hedonic scale scored as follows: *dislike extremely* = 1, through *neither like nor dislike* = 5, to *like extremely* = 9. Panelists evaluated fluctuating and constant-temperature food pairs one at a time in sequential counterbalanced order. They were unaware of sample treatments and were encouraged to make additional comments. Except for the cocoa beverage which was served hot [≈ 74°C (165°F)], all other foods, including entrees, were served at room temperature [≈ 21°C (70°F)].

RESULTS AND DISCUSSION

Table 3 contains observations from sensory screenings of all MRE XII ration components after 12 weeks (six cycles) storage at fluctuating temperatures. Food technologists did not consider any of the changes noted major defects in view of the temperature cycles to which the foods were exposed.

Mean hedonic ratings from consumer acceptability panels are given in Table 4. After 12 weeks (six cycles) at fluctuating temperatures, 6 of the 20 products rated significantly ($p \leq 0.05$) lower than their constant temperature stored counterparts: chicken stew and chicken with rice entree, thermostabilized applesauce and peaches, crackers, and sucrose-based orange beverage. None of the decreases in mean ratings for fluctuating temperature stored components, statistically significant or not, could be considered "dramatic," all were less than one scale point; the exception: applesauce, 1.4 scale points.

Comments volunteered by consumer panelists were examined when statistically significant differences in ratings occurred. Compared to constant temperature samples, comment patterns for fluctuating temperature sample characteristics were as follows:

Applesauce: (1) One fourth of the panel that commented noted negatively-associated flavor and texture characteristics not found in constant temperature samples - "oxidized, sour, bad aftertaste" for flavor, and "texture too fine, like baby food, watery" for texture.

Table 3. Sensory Changes Noted in MRE XII Components After Six Fluctuating Temperature Cycles (12 Weeks)

Component	*Changes*	*Observations [Compared to 4° C (40° F) Reference Sample]*
Applesauce	*AFT*	*V. slightly darker, thinner, sl. decreases in flavor*
Aspartame Sweetened Beverages:		
Lemonade	*F*	*V. slightly less sweet*
Fruit Punch	*A*	*Slightly darker in color*
Beef Frankfurters	*A*	*Darkening of color*
Beef Stew	*AFT*	*Meat slightly darker, slightly watery & stringy*
Charms	*AF*	*Stick to package, rancid oil flavor*
Cheese Spread	*AT*	*Darker color & oily mouthfeel*
Chicken & Rice	*AT*	*V. slight color change, increase in dry & chewy*
Chicken Stew	*AT*	*Mushy, watery*
Chocolate Covered Brownie	*F*	*More flavorful*
Chocolate Covered Cookie Bar	*A*	*V. Slight color change*
Chocolate Mint Pound Cake	*AT*	*Slight color change & V. slightly grainy*
Cocoa Bev. Powder	*F*	*Old dry stale milk*
Corned Beef Hash	*FT*	*Slightly bitter & slightly watery*
Crackers	*AT*	*V. slightly darker & more crispy*
Dehydrated Fruit Mix	*AT*	*V. slightly gummy*
Escalloped Potatoes w/Ham	*AT*	*Ham slices darker & drier, potatoes watery*
Grape Jelly	*A*	*Very slight syneresis*
Green Gum	*AFT*	*Borderline, discolored v. slightly stale*
Ham Slices w/Natural Juices	*AT*	*Gelatin is more liquid, stringy, chewy mouthfeel*
Instant Coffee	*AF*	*V. slightly darker, off flavor*
Instant Coffee w/Creamer		*No change*
Lemon Lime Bev. Base Powder		*No change*
Lemon Pound Cake	*AFT*	*V. slightly dry, soapy aftertaste & grainy*
Mars Bar	*F*	*Old dry milk flavor*
M&M's Candy	*AF*	*More flavorful, v. slight dullness of color*
Oatmeal Cookie Bar		*No change*
Omelet	*T*	*grainy*
Peaches, Wet Pack		*No change*
Peaches, Dehydrated	*FT*	*V. slightly more sweet & slimy*
Peanut Butter	*FT*	*V. slight increase in oil flavor, sl. less sticky*
Pears, Dehydrated	*T*	*V. slightly slimy*
Pork Chow Mein	*T*	*Slightly mushy*
Pork w/Rice and BBQ Sauce	*AT*	*Slightly darker & slightly more fluid*
Potato Sticks		*No Change*
Potato au Gratin	*FT*	*Bitter metallic, very watery*
Spaghetti w/Meat Sauce	*FT*	*Slight bland flavor & slightly mushy*
Sugar (Domino)		*No change*
Sugar Sweetened Beverages:		
Cherry Bev. Base Powder		*No change*
Grape Bev. Base Powder		*No change*
Orange Bev. Base Powder		*No change*
Tabasco Sauce	*A*	*V. slight change in color*
Tootsie Roll	*FT*	*Slight off flavor, very hard to chew*
Tuna w/Noodles	*AFT*	*Tuna dry & bland, very mushy*
Vanilla Pound Cake	*AFT*	*Slightly dry, v. slightly more gummy*

* *A = Appearance, F = Flavor, T = Texture*

Table 4. Mean Hedonic Ratings[a] of Meal, Ready-to-Eat Components Stored 12 Weeks at Constant 4°C (40°F) and After Six, 2-Week Fluctuating Temperature Cycles

Components	Constant	Fluctuating
Entrees	Mean ± Std. Dev[a]	Mean ± Std. Dev.[a]
Beef Stew	6.9 ±1.2	6.6 ±1.3
Chicken Stew	6.2 ±1.5	5.8 ±1.7[b]
Chicken w/Rice	5.6 ±1.9	5.2 ±2.0[c]
Escalloped Potatoes w/ Ham	6.6 ±1.3	6.4 ±1.2
Frankfurters	6.6 ±1.8	6.5 ±1.7
Pork Chow Mein	4.8 ±1.9	5.1 ±1.8
Spaghetti w/Meat Sauce	5.7 ±1.9	5.6 ±1.8
Tuna w/Noodles	5.0 ±2.1	4.9 ±1.9
Fruits		
Applesauce	7.5 ±1.0	6.1 ±2.1[c]
Peaches, Dehydrated	4.8 ±1.9	5.1 ±1.8
Peaches, Wet Pack Processed	7.1 ±1.2	6.4 ±1.6[c]
Baked & Snack Items		
Chow Mein Noodles	7.1 ±1.2	6.8 ±1.6
Potato Sticks	7.3 ±1.1	7.2 ±1.1
Crackers	6.0 ±1.6	5.6 ±1.6[b]
Beverages (Sweetener)		
Cherry (sugar)	6.5 ±1.4	6.6 ±1.4
Hot Cocoa (sugar)	6.6 ±1.1	6.4 ±1.4
Grape (sugar)	6.3 ±1.0	6.3 ±1.4
Lemonade (aspartame™)	6.2 ±1.4	6.5 ±1.2
Lemon-Lime (sugar)	5.6 ±1.6	5.4 ±1.7
Orange (sugar)	5.5 ±1.6	4.8 ±1.9[c]

Footnotes: [a] 9-Point Scale: 1 = *Dislike Extremely*, 5 = *Neither Like Nor Dislike*, 9 = *Like Extremely*. Std. Dev. = Standard Deviation of the Mean

[b] Significantly lower rating than constant temperature sample, $p \leq 0.05$

[c] Significantly lower rating than constant temperature sample, $p \leq 0.01$

Crackers: Comments for both samples were the same as those typically received for the MRE cracker formulation - "dry, bland, needs salt, too thick and coarse." Differences between the samples could not be distinguished by the comments.

Orange beverage: One-third or more of the panelists commented negatively on both samples, but comments were more strongly worded and more numerous for the fluctuating temperature sample. Orange flavor of the former sample was described as "can't tell it was orange, artificial, not fruity;" for the latter sample, it was described as "bad, terrible, worse than anything, plain/no flavor, medicinal, powdery, no resemblance to orange."

Peaches, Wet Pack: (1) one-third of panel commented on "mushy, too soft" texture not noted in the constant temperature sample: (2) 2 comments on darkening or brownish color; (3) 5 comments on "odd taste, lack of peach flavor."

The authors consider the fluctuating temperature program to which the MRE components were exposed atypically stressful since it included *both* low and high temperature stresses. Although the food technologists (Table 3) typically indicated slight adverse color, flavor and texture changes for these samples compared to control samples, they did not record certain changes in fluctuating-temperature stored wet pack peaches and orange beverage observed by consumer panelists. Peaches for retort pouches, as presently procured, are repacked from bulk No.10 cans, and high pouch-to-pouch texture variability is possible, as noted by Kluter et al., 1994; high constant-storage temperatures produce significant tissue softening. For the orange beverage, orange flavor components, such as limonene, might have reacted with the food contact polypropylene layer during the temperature cycles, resulting in a marginally acceptable beverage. In this instance also, the consumer panel noted a worsening of the flavor defect not recorded by the food technologists. No other unusual physical changes, such as the blooming seen in the desert chocolate bar, were observed in the rest of the MRE components evaluated.

A mean rating of 5 (neither like nor dislike) has historically been a minimum score benchmark for considering a stored ration acceptable. Serving the entree items "cold," i.e., room temperature, might have depressed entree ratings, but probably did not affect magnitude of differences between sample pairs. Some constant temperature samples in the entree, fruit and beverage categories were only marginally acceptable (mean ratings 5.0 to 5.7). Of the 20 products, only the orange beverage rating decreased from marginal liking to disliking (5.5 to 4.8), suggesting it might be unacceptable for consumption if subjected to extremely fluctuating temperatures. The tuna with noodles entree, marginally acceptable when stored at 40°F (5.0), was removed from subsequent MRE menus because other soldier consumer field data and complaints have documented unacceptability of the item itself.

Temperature Data, Storage Cabinet

To evaluate the temperature cycles to which the MRE components were exposed, four factors must be considered: (1) mean temperature, (2) effective mean temperature, (3) the extreme temperatures and (4) freeze thaw transitions. The measured mean temperature over the six cycles was 15.6°C (60°F), corroborated to within ±1.7°C (3°F) by the temperature recorders. The cyclic temperature schedule used in this study resembled square wave heating cycles. The time temperature indicator (TTI) labels used to monitor temperature stresses on stored MREs

assume an activation energy (E_a) of 26,000 calories per mole. At this activation energy, the effective mean temperature, T_e, may be computed, using the following formula:

$$T_e = T_r / 1 + x_e$$

where (1) T_r = reference absolute temperature and (2) x_e = effective inverse temperature over the six cycles (Ross, 1995) at an activation energy (Ea) of 26,000 cal/mole.

Using the above formula, the effective mean temperature would be 38.3°C (101°F). However, these calculations are further complicated by temperatures below freezing which are not relevant to these activation energies.

Conclusions and Recommendations

This study has indicated the potential for adverse sensory changes in quality and acceptability for MRE components when exposed to extremely stressful fluctuating temperatures. In general, the extent of these changes were not as great as anticipated. However, these data indicate that a significant lowering of acceptability can be expected in entree items containing chicken and the wet pack fruits. The other items - entrees, baked and snack, and beverages - can be expected to remain relatively stable. In general, sensory changes observed in the fluctuating-temperature stored MRE components appeared comparable to those typically observed in the same items after three months storage at constant 38°C (100°F) temperatures. Because some MRE components may be sensitive to deterioration under fluctuating temperatures, the most important caveat from this study is that these stressful conditions should be avoided or minimized to maintain all menu components at the highest possible acceptance level.

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